LOAD VARIATION INFLUENCES ON JOINT WORK DURING SQUAT EXERCISE IN REDUCED GRAVITY

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INTRODUCTION

Resistance exercises that load the axial skeleton, such as the parallel squat, are incorporated as a critical component of a space exercise program designed to maximize the stimuli for bone remodeling and muscle loading. Astronauts on the International Space Station perform regular resistance exercise using the Advanced Resistive Exercise Device (ARED).

Squat exercises on Earth entail moving a portion of the body weight plus the added bar load, whereas in microgravity the body weight is 0, so all load must be applied via the bar. Crewmembers exercising in microgravity currently add ~70% of their body weight to the bar load as compensation for the absence of the body weight. This level of body weight replacement (BWR) was determined by crewmember feedback and personal experience without any quantitative data.

The purpose of this evaluation was to utilize computational simulation to determine the appropriate level of BWR in microgravity necessary to replicate lower extremity joint work during squat exercise in normal gravity based on joint work. We hypothesized that joint work would be positively related to BWR load.

METHODS AND PROCEDURES

Six subjects (3M/3F) completed a squat exercise in normal gravity on the ground-based ARED at NASA Johnson Space Center. Motion capture data were collected at 250 Hz with a twelve-camera motion capture system (SMART-D, BTS Bioengineering SPA, Milanese, IT). Ground reaction force (GRF) data were collected bilaterally at 1000 Hz by independent force platforms (Kistler Model 9261, Kistler Instruments AG, Winterhur, Switzerland). Data were collected simultaneously on a single workstation.

OpenSim software (OpenSim 2.2.0, Simbios, Palo Alto, CA) was used to determine lower extremity kinematics and joint torques at the ankle, knee and hip (Delp et al., 2007). The base model used for the analysis was a generic musculoskeletal model with 23 degrees of freedom that accompanied the OpenSim software (Delp et al., 1990).

Subject-specific models were created based on anthropometry. The hip joint was modeled as a ball and socket joint (3 dof) while the knees and ankles were modeled as hinge joints (1 dof). For this analysis, we focused on motions in the sagittal plane.

Once inverse kinematic analyses were completed, the joint torques at the ankle, knee and hips were computed using an inverse dynamics analysis. Instantaneous joint power was computed as the product of torque and angular velocity. Positive work for the concentric (upward) phase was found by integrating the power versus time curve. All computations were performed with custom scripts using MATLAB (Version R2010a, MathWorks, Natick, MA). All simulations were initially completed at 1-**g** and subsequently performed for comparison to a 0-**g** condition with BWR loads of 0%, 30%, 50%, 70%, and 100%. BWR simulations were

completed by reducing the GRF data for a given condition by the appropriate percentage of body weight and assuming that joint kinematics in 0-**g** were the same as in 1-**g**.

Linear regression was used to determine the relationship between joint work and BWR load. The BWR load necessary to replicate the work performed in 1-**g** at each joint was found using the derived regression equations relating work to BWR level. Separate analyses were performed for each subject.

RESULTS

For all joints, net work was related to BWR (r^2=0.99±0.01) The mean BWR to replicate 1-**g** net positive work in the lower extremities was 66.77±4.92%, 88.30±4.17%, and 96.05±1.26% for the hips, knees, and ankles, respectively. Figure 1 illustrates the relationship between net joint work and BWR. Work values are normalized by 50% of the body weight + resistance load.
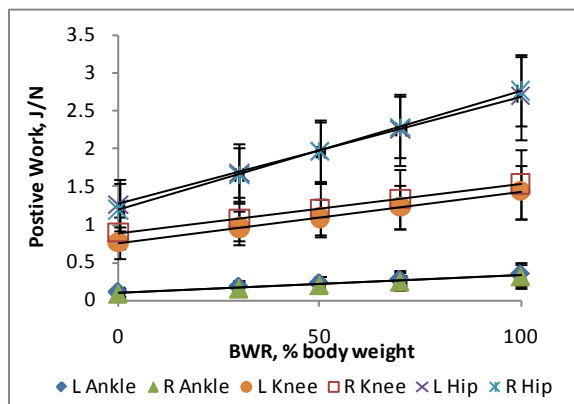
Figure 1: Normalized positive work vs. BWR for all subjects (mean±s.d.).

DISCUSSION

Simulation results suggest that with the current BWR of 75% used by crewmembers, musculature at the hip may be loaded sufficiently while the knees and ankles are underloaded compared to 1-**g**. Using body segment parameters of de Leva (1996), approximately 59%, 88%, and 97% of body mass is above the hips, knees, and ankles respectively. Our results suggest that using superior net body mass anatomically superior to the joint of interest to guide BWR may be acceptable for the knees and ankles, but may not be sufficient for the hips. More study is necessary to determine BWR influences on specific musculature, and if similar relationships occur with other axial loading exercises.

CONCLUSIONS

Our approach using simulation has allowed us to provide some evidence that current squat exercise prescriptions for crewmembers may be sufficient to load the hips, but may underload the knees and ankles. Simulations were completed using existing data at a fraction of the cost of completing an experiment in actual or simulated 0-g.

REFERENCES

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